

AS Unit BY2: Biodiversity and Physiology of Body Systems

Name:

Date:

Topic 2.3 Transport (Plants) – Page 1A

(d) Structure of the dicotyledon root. Absorption of water. Movement of water through the root: apoplast, symplast and vacuolar pathways. Structure and role of endodermis. The structure of xylem. Movement of water from root to leaf. Transpiration stream, cohesion-tension theory. Environmental factors affecting transpiration. Angiosperm adaptations: hydrophytes, xerophytes

(e) The structure of phloem as seen by the light and electron microscope. Translocation of organic materials from source to sink. Phloem transport: diffusion; cytoplasmic strands; mass flow models. Experimental evidence that solutes e.g. sucrose, are carried in the phloem. Use of aphids and autoradiographs. *

Suggested Practical Activities: Examination of TS primary stem dicotyledon and root. TS and LS primary xylem and phloem. The use of a simple potometer. Computer modelling may be used to extend this investigation. TS leaf marram grass and water lily. Examination of epidermal strips and/or replicas to compare stomatal numbers in leaves adapted to different environments. Examination of TS artery and vein. Observation of erythrocytes and leucocytes in prepared blood smears.

Prior to AS level you probably only looked at the functions of xylem and phloem. In unit 2.1 you should also draw in your knowledge of the cohesive, adhesive and transport properties of water.

		Completed
1.	Structure of Dicotyledonous Roots and the Transport of water and nitrogen into the plant. <ul style="list-style-type: none"> What are the tissues found in roots and how are they distributed? How does water enter the root and travel to the xylem vessels? What is the Casparian strip? 	
2.	Read page 4-6 Transport of water into and across the roots Complete tasks on the pages.	
3.	Read page 7-8 Structure of Stems Complete the questions and tasks on pages 7-8	
4.	Read pages 9-11 Passage of Water up the Plant – Transpiration Complete all questions	
6.	Read pages 12-14 on Mesophytes, hydrophytes and xerophytes and answer the questions.	
7.	Explain why transpiration in plants is: <ul style="list-style-type: none"> i. inevitable ii. desirable iii. Undersirable 	

End of topic checklist for 2.3 Transport

Tick as appropriate:

RED: I do not know about this

AMBER: I have heard about this but have not learned this yet. I am unsure on this.

GREEN: I have heard about this and I have learned this. I am confident about this.

1. Candidates should be able to draw a dicotyledonous root to show position of vascular tissue.			
2. Most absorption of water is through the root hairs, which provide a large surface area and are freely permeable.			
3. Soil solution soaks into the walls of epidermal cells and travels across the cortex through the cell walls or through the spaces between cells, drawn by the transpiration stream; this is the apoplast route.			
4. Water can also cross the plasma membrane by osmosis.			
5. If it then moves through the cytoplasm of cells via plasmodesmata; this is the symplast route.			
6. Water can also travel through cell vacuoles; the vacuolar pathway.			
7. The endodermis is a layer of cells that surround the pericycle within which lies the vascular tissue (stele).			
8. The endodermic apoplast route is blocked by the Casparian band located tangentially in the cell wall and made of waterproof suberin.			
9. At the Casparian band water passes across the plasma membrane and continues along the symplast route.			
10. Since the xylem lacks cell contents the water is transferred to the apoplast in the pericycle.			
11. Nitrogen usually enters the plant as nitrate ions/ammonium ions which diffuse along the concentration gradient into the apoplast stream but enter symplast by active transport against the concentration gradient and then flow via plasmodesmata in the cytoplasmic stream.			
12. At the endodermis ions must be actively taken up to by-pass the Casparian band, which allows the plant to selectively take up ions at this point.			
13. This lowers the water potential in the xylem, causing water to be drawn through the endodermis.			
14. This produces a positive hydrostatic pressure inside the xylem, forcing water upwards. This positive pressure is known as root pressure.			
15. Candidates should be able to draw the structure of the stem of a dicotyledon to illustrate the position of transporting tissue.			
16. Xylem consists of dead, lignified tracheids and vessels with pits, supporting fibres and living parenchyma.			
17. Tracheids and vessels form a continuous system of channels for water transport.			
18. Water passes through the root to the xylem, up through the stem to the leaves where most evaporates.			
19. The columns of water in the xylem are held up by the cohesive force between water molecules and the adhesive forces between water molecules and the hydrophilic lining of the xylem vessels.			
20. Transpiration is the loss of water from the leaves which gives rise to the transpiration stream. The continued removal of water molecules from the top of the xylem vessels results in a tension causing a pull on the xylem column.			
21. Transpiration is affected by various external factors such as temperature, humidity and air movement.			
22. The opening and closing of stomatal pores can alter water loss through transpiration.			
23. Plants can be classified, on the basis of structure in relation to the prevailing water supply, into hydrophytes, mesophytes and xerophytes.			
24. Hydrophytes, e.g. water lily, live with their roots submerged in mud at the bottom of a pond and have floating leaves on the surface.			
25. Hydrophytes have little need for support or transport tissues; have little or no cuticle and stomata only on the upper surface of their leaves. There are large air spaces present in both stem and leaf tissue.			

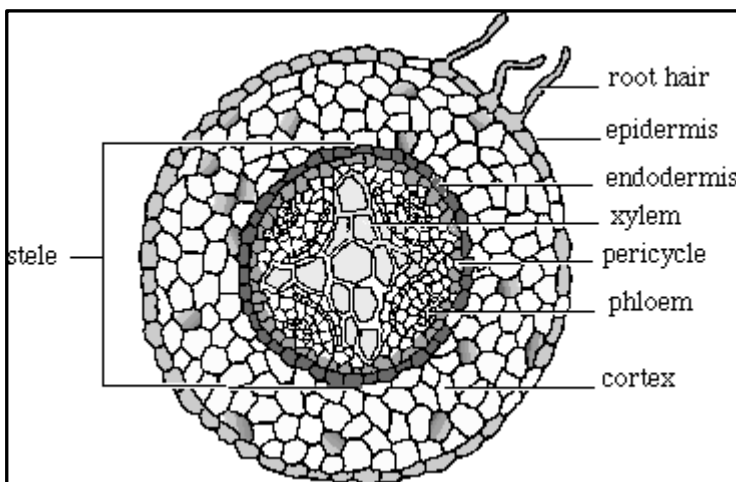
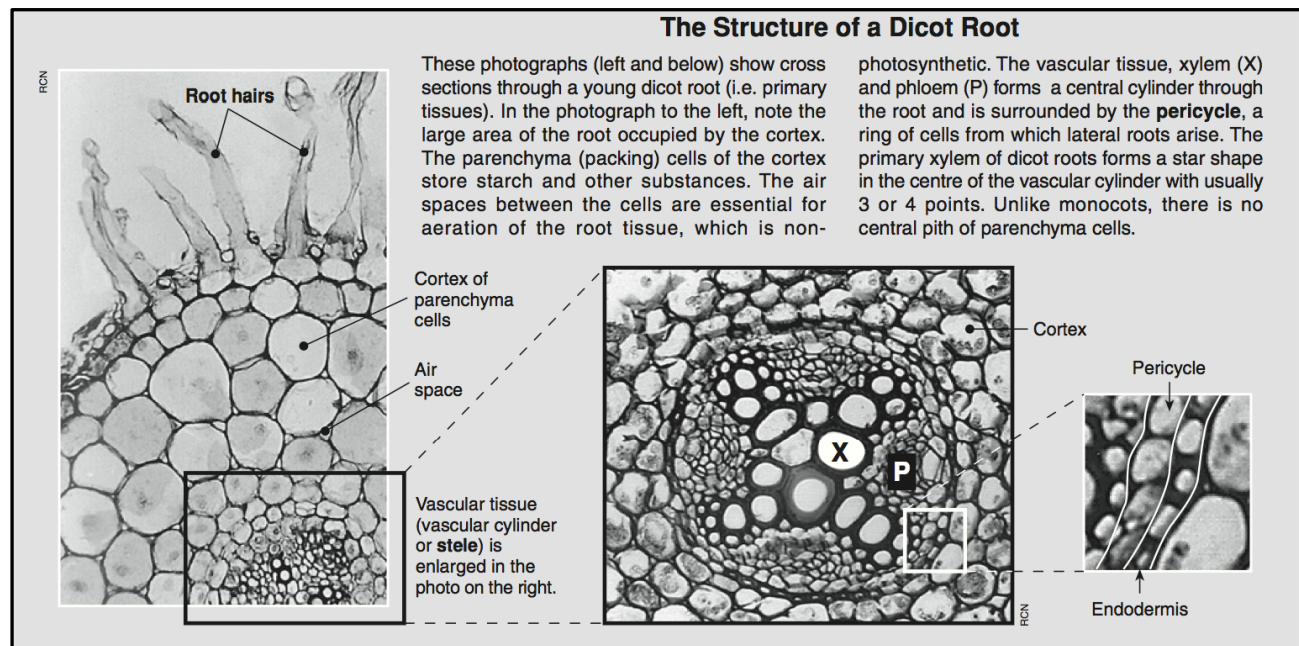
26. Xerophytes have adapted to living under conditions of low water availability so have modified structures to prevent excessive water loss.			
27. Marram grass demonstrates the role of a xerophyte with its leaf shape, sunken stomata, thick cuticle and hairs in reducing water loss.			
28. Mesophytes are plants of temperate regions and flourish in habitats with adequate water supply. They need to survive unfavourable times of the year by shedding their leaves, surviving underground or as dormant seeds.			
29. Phloem consists of sieve tubes and companion cells linked by plasmodesmata with fibres and parenchyma.			
30. The products of photosynthesis are transported in soluble form (sucrose) to all parts of the plant in the phloem.			
31. The leaves are a source of sugars and the growing regions act as a sink.			
32. Early evidence about translocation of solutes was obtained from ringing experiments.			
33. The technique of radioactive tracing combined with using aphid mouthparts demonstrated that translocation is a rapid process.			
34. Radioisotope labelling using carbon dioxide combined with autoradiography shows that sucrose is transported bi-directionally to sinks.			
35. The mass flow hypothesis suggests that there is a passive flow of sucrose from source to sink. (no details required)			
36. The mass flow hypothesis does not account for all observations such as movement in opposite directions at the same time and at different rates.			
37. Other hypotheses have been proposed; including diffusion and cytoplasmic streaming.			

Uptake and Transport of Water

Plants and animals require water for essentially the same reasons. It is the medium in which all metabolic reactions take place; it is needed for hydrolysis and for the transport of solutes around the organism. In addition it provides turgor pressure, which helps to support the organism.

Uptake of Water by the Roots

The roots provide the surface through which water is taken up. Thousands of root hairs that are found just behind the root tip greatly increase the surface area for water uptake. The root hairs are confined to the part of the epidermis immediately behind the tip, further back they will be sloughed off through abrasion as the root pushes through the soil particles. Each root hair cell is a slender extension of an epidermal cell up to 4mm long.



The root hairs penetrate between the soil particles and are in close contact with the soil water. The root hairs are freely permeable to water and water enters the root from the soil, down a gradient of water potential.

Behind the epidermis, large thin-walled **parenchyma** cells make up the **cortex**, which constitutes the main body of the root. In the centre there is a core of vascular tissue, which contains lignified **xylem cells** and **phloem cells**.

The endodermis is a layer of cells, which surround the **pericycle** within which is the vascular tissue (**stele**).

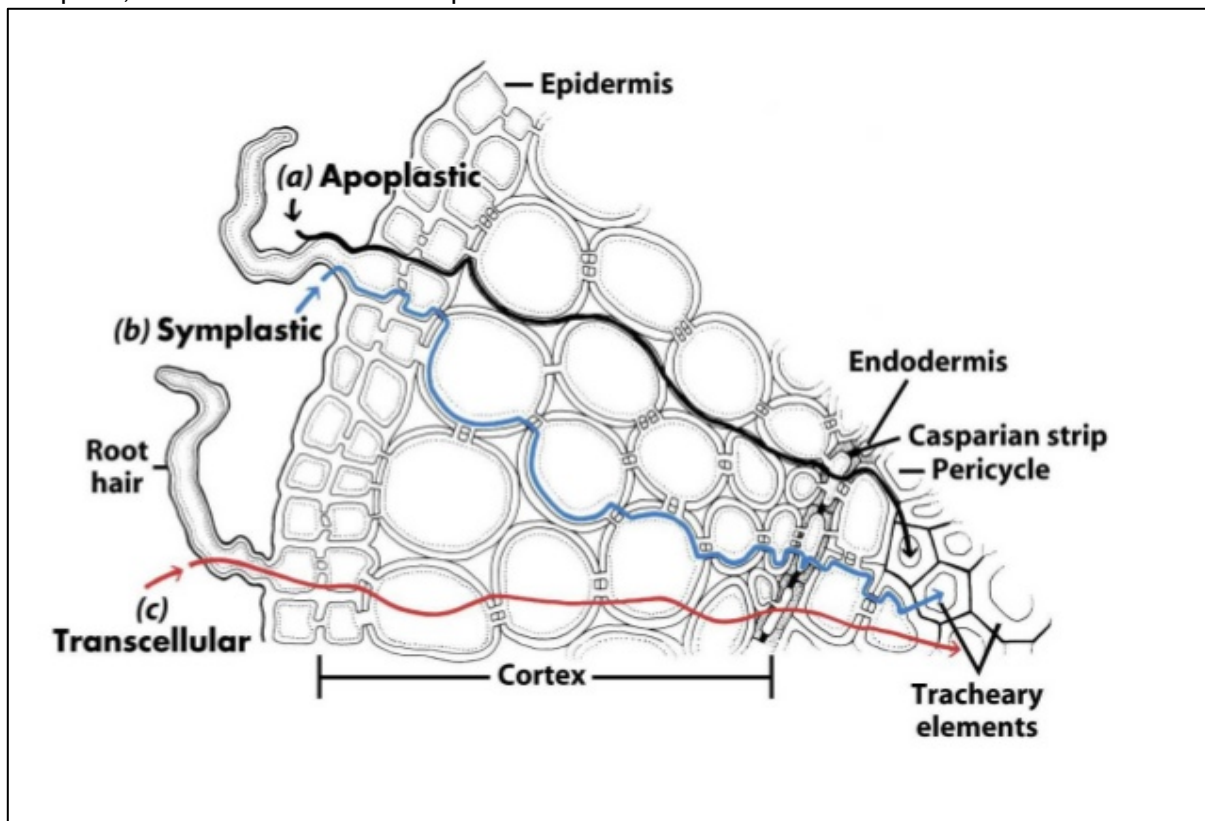
Draw a simplified plan diagram of the root:

The pathway taken by water

Water mainly enters the root down a water potential gradient. The soil water only contains a very weak solution of mineral salts and so has a high water potential.

Once inside the root the water follows three pathways across the cortex:

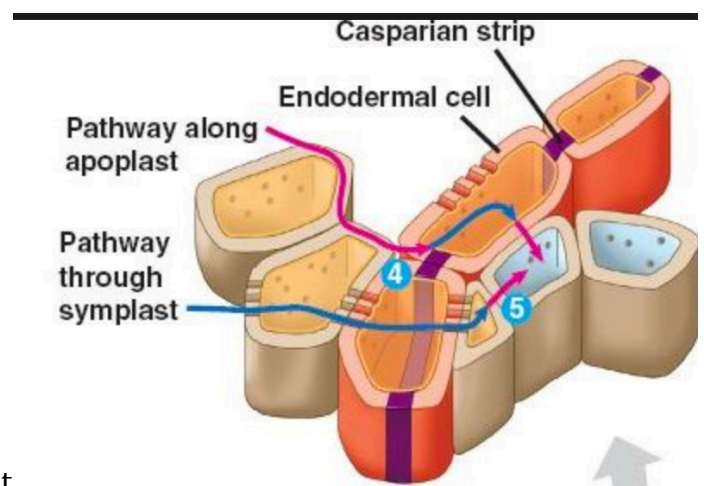
- The **apoplast pathway**: this pathway follows the interconnected cellulose cell walls of adjacent cells. The water flows in the spaces between the cellulose microfibrils, the pull is provided by the transpiration stream.
- The **symplast pathway**: this consists of the cytoplasm, which is continuous from cell to cell via the **plasmodesmata**. To reach the symplast (inside the cell membrane) water has to cross the partially permeable membrane by osmosis.
- The **vacuolar pathway** water passes across the epidermal cell wall, plasma membrane and tonoplast, then into the vacuole. It passes to the next cell in the same manner.



- Change the Transcellular to the **vacuolar pathway**
- Label some plasmodesmata
- Label a cellulose cell wall of a cell in which the **apoplast pathway** is taking place
- Label the symplast of a cell in which the **symplast pathway** is taking place.

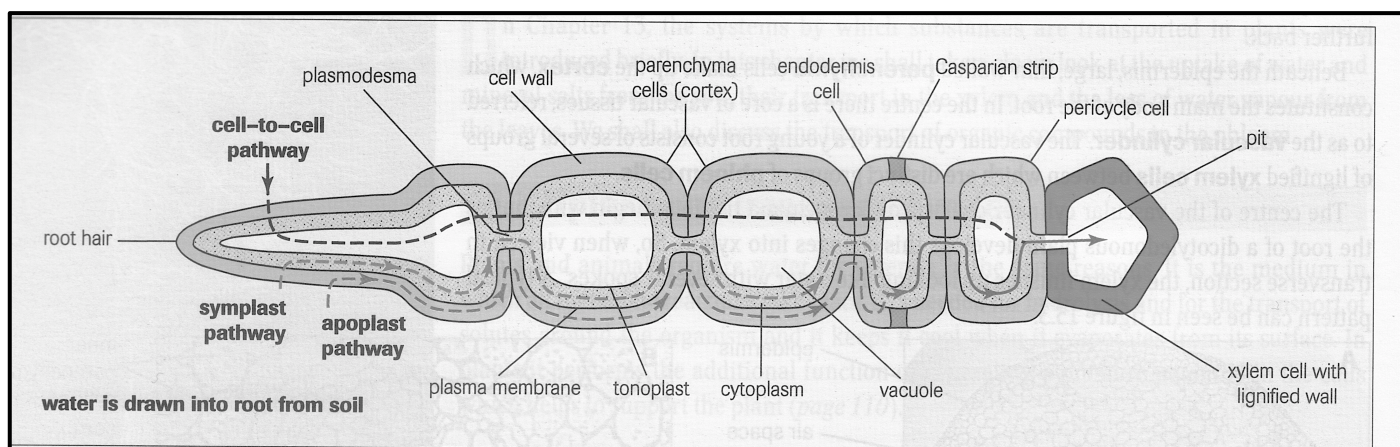
Once the water reaches the **endodermis**, its flow is prevented by an impermeable thickening of **suberin** in the walls of endodermal cells, this is known as the **Casparian band**. This Casparian band diverts water from the cell walls, and prevents the use of the apoplast pathway, forcing it to take the symplast pathway through the endodermal cells.

It is thought that endodermal cells actively transfer salts from the cortex to the pericycle. The resulting high concentration of salts in the pericycle creates a



low water potential which cause water to move into them by osmosis from the cortex, through the partially permeable membranes of the endodermis cells.

In summary salts are actively transferred across the endodermis and the water follows passively. Once in the pericycle, the water flows into the xylem down a water potential gradient in both symplast and apoplast pathways. Once in the xylem due to the fact that xylem cells lack cell contents the water is transferred to the apoplast pathway.



Uptake of Minerals

Minerals such as ammonium and nitrate ions are usually taken up by the root hairs by active transport from the soil solution. Once absorbed, the mineral ions may move along the apoplast pathway carried into solution by the water and being pulled along by the transpiration stream.

When minerals reach the endodermis and the **Casparian Band** the ions enter the cytoplasm of the cell by active transport from where they diffuse or are actively transported into the xylem. At the endodermis because ions need to be actively taken up this allows the plant to selectively uptake ions.

Describe the 3 routes along which water moves across the cortex of the root from the epidermal layer to the central tissue (note these 3 routes are also used as water moves from the xylem vessels across the mesophyll cells in the leaf).

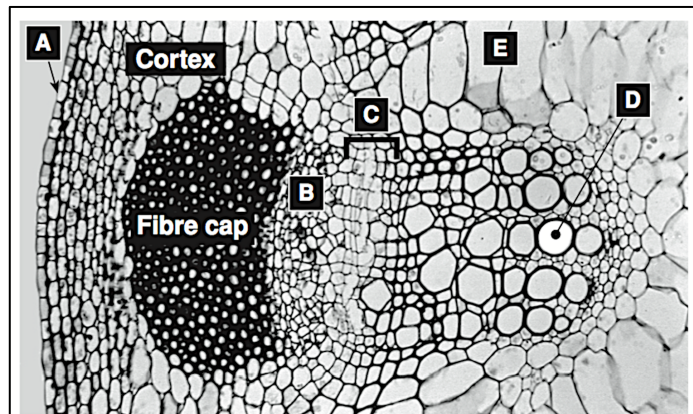
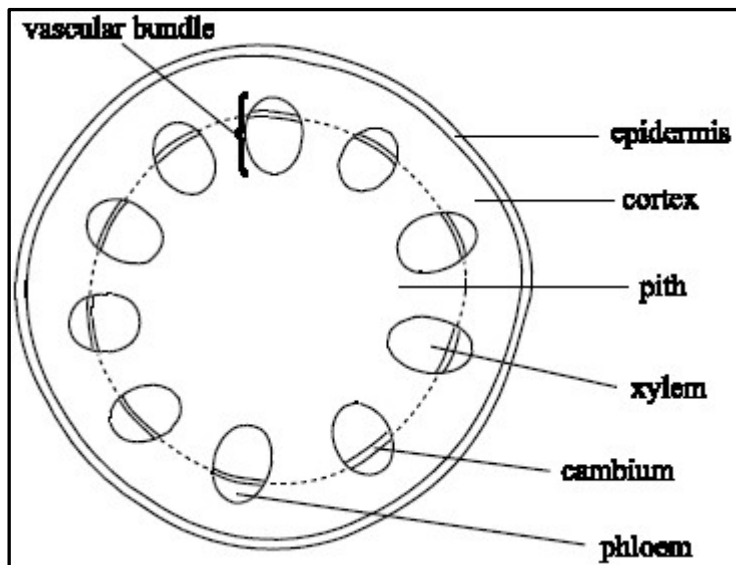
Explain the role of the **Casparian Band** in the endodermis.

Transport of Water from the Root to the Leaf

Water is transported from the roots to the leaves via the stem.

Internal Structure of the Stem

In dicots, each vascular bundle contains **xylem** (to the inside) and **phloem** (to the outside). Between the phloem and the xylem is the **vascular cambium**; a layer of cells that divide to produce thickening of the stem. The middle of the stem is called the **pith**, it is filled with thin walled **parenchyma** cells.



Looking at the figure on the right hand side, which shows a light micrograph of part of a stem, try to identify parts A to E.

A _____

B _____

C _____

D _____

E _____

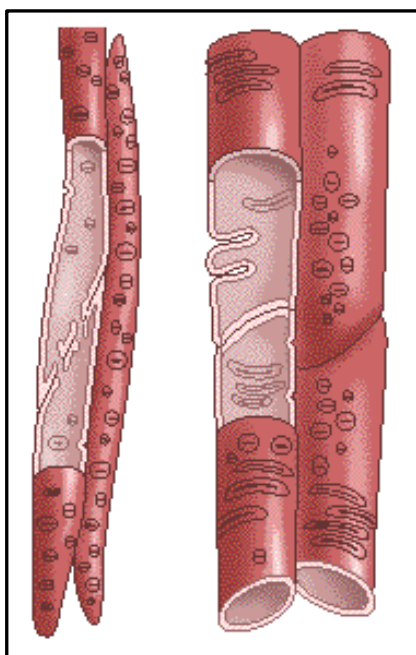
Draw and label a plan diagram of a stem below:

Xylem Tissue

Xylem is the principal **water conducting tissue** in vascular plants. It is also involved in transporting dissolved minerals.

Xylem is a **complex tissue**. In angiosperms, it is composed of five cell types: tracheids, vessels, xylem parenchyma and fibres. Tracheids and vessels are the major transporting tissues; they are heavily strengthened with lignin. Parenchyma is involved in storage and fibres lend strength.

Xylem contains two types of conducting cells: **tracheids** and **vessels**. These are dead cells and they form a system of pipes through which water can travel. The cells are dead because once they have reached their full size, their cellulose cell walls become impregnated with **lignin**, which is impermeable to water, and solutes. The cells die leaving the cell walls surrounding a fluid filled cavity.



Cell A

Cell B

Vessels are characteristic of angiosperm and are absent from the xylem tissue of conifers. Tracheids occur in all conifers and all angiosperms.

Vessels provide little resistance to the movement of water this is because the end walls of the vessels have broken down and form a continuous cylindrical pipe.

Tracheids provide more resistance as the end walls remain intact and are perforated only by small holes called **pits**.

Pits occur in the walls of both vessels and tracheids. Where a pit occurs lignin fails to deposit and only cellulose remains. This permits the passage of water sideways as well as upwards.

Name cells A and B.

State one way in which the structure of cell A differs from cell B.

In which tissue are these cells found?

State two functions of these tissues:

Describe 3 ways in which cell B is adapted for its function in the plant.

The Ascent of Water up the Stem

Root Pressure

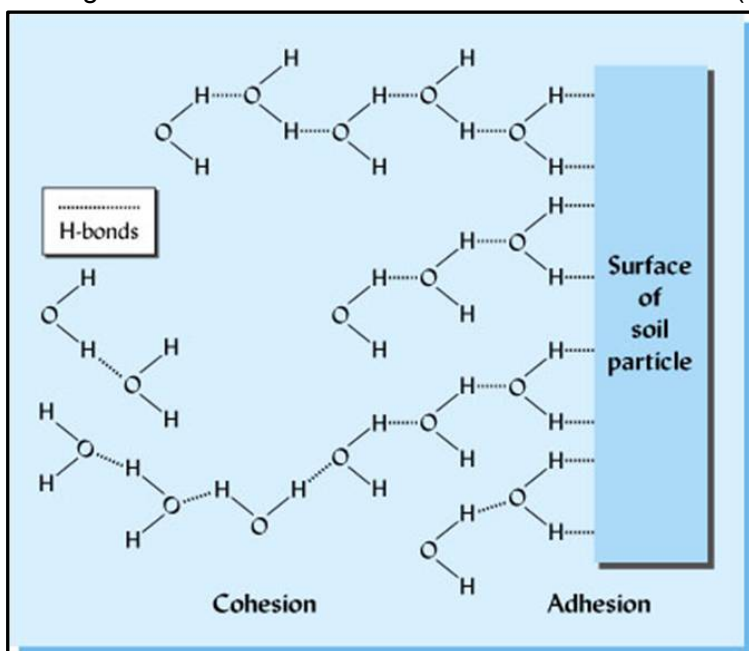
This is as a result of osmotic flow across the endodermis, the necessary water potential gradient being created by the active transport of salts from the cortex to the pericycle (see page 5).

Root pressure provides a force that pushes water up the stem.

Transpiration

Water travels up through the stem into the leaves, where most of it evaporates from the internal leaf surface and passes out as water vapour, into the atmosphere. The water lost in this way is replaced by water drawn up through the xylem tubes in what is called the **transpiration stream**. Continuous columns of water therefore hang from the top of the plant; two forces holding them there are **adhesion** and **cohesion**.

Distinguish between the terms adhesions and cohesion (include why water is exhibits these properties):



The lining of the xylem vessels is hydrophilic, why is this important?

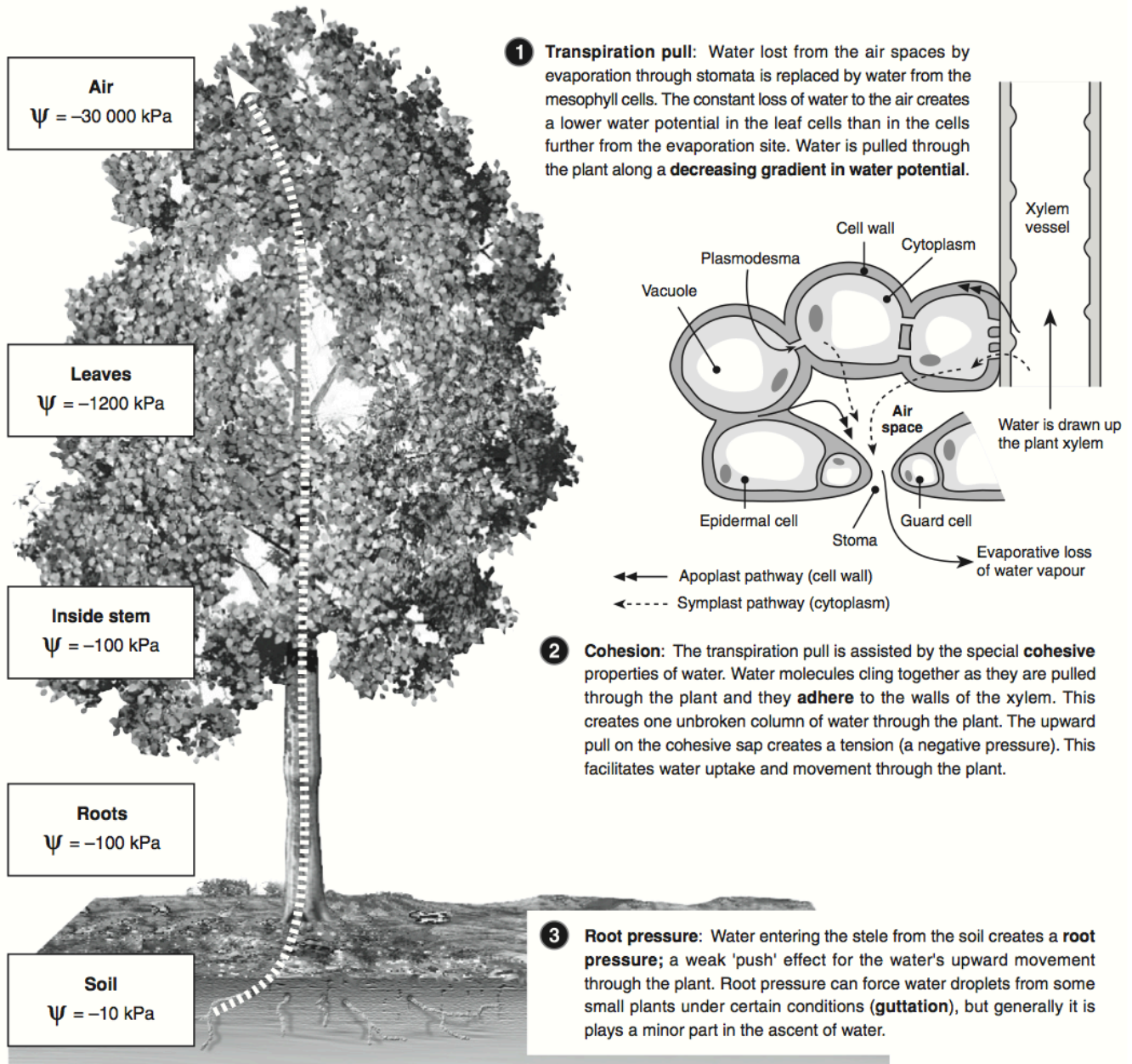
The **cohesion-tension** theory is often used to explain the rise of water in the xylem of all plants. Cohesive forces between water molecules hold the continuous columns of water together, and when water transpires from the leaf the whole of the water column moves up the plant.

From Leaf to the Air

The stomata as well as permitting the entry of carbon dioxide, allow the evaporation of water from the plant, the phenomenon known as **transpiration**. The effective evaporating surface of the leaf consists of saturated spongy mesophyll cells. The water evaporates and moves down a gradient of water potential from the plant to the atmosphere, through the stomatal pores.

Plants lose water all the time, despite the adaptations they have to help prevent it (e.g. waxy leaf cuticle). Approximately 99% of the water a plant absorbs from the soil is lost by evaporation from the leaves and stem. This loss, mostly through stomata, is called **transpiration** and the flow of water through the plant is called the **transpiration stream**. Plants rely on a gradient in water potential (ψ) from the roots to the air to move water through their cells. Water flows passively from soil to air along

a gradient of decreasing water potential. The gradient in water potential is the driving force in the ascent of water up a plant. A number of processes contribute to water movement up the plant: transpiration pull, cohesion, and root pressure. Transpiration may seem to be a wasteful process, but it has benefits. Evaporative water loss cools the plant and the transpiration stream helps the plant to maintain an adequate mineral uptake, as many essential minerals occur in low concentrations in the soil.



- (a) Plants constantly lose water by transpiration. Explain how plants compensate for this: _____

(b) Describe one benefit of the transpiration stream for a plant: _____

- Briefly describe three processes that assist the transport of water from the roots of the plant upward:

(a) _____

(b) _____

(c) _____

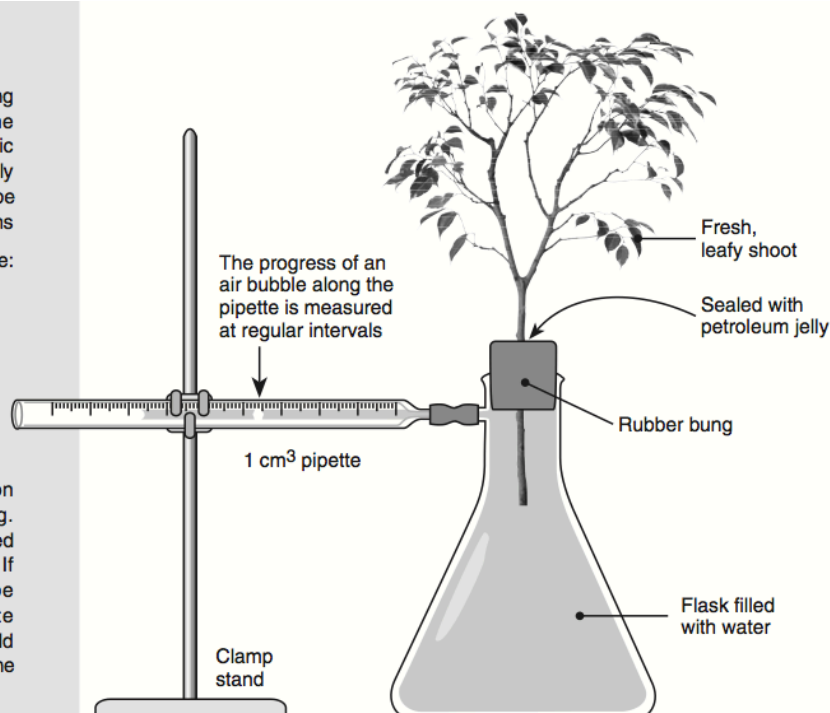
The Potometer

A potometer is a simple instrument for investigating transpiration rate (water loss per unit time). The equipment is simple and easy to obtain. A basic potometer, such as the one shown right, can easily be moved around so that transpiration rate can be measured under different environmental conditions

Some of the physical conditions investigated are:

- Humidity or vapour pressure (high or low)
- Temperature (high or low)
- Air movement (still or windy)
- Light level (high or low)
- Water supply

It is also possible to compare the transpiration rates of plants with different adaptations e.g. comparing transpiration rates in plants with rolled leaves vs rates in plants with broad leaves. If possible, experiments like these should be conducted simultaneously using replicate equipment. If conducted sequentially, care should be taken to keep the environmental conditions the same for all plants used.



3. Describe three environmental conditions that increase the rate of transpiration in plants, explaining how they operate:

- (a) _____
- (b) _____
- (c) _____

4. The **potometer** (above) is an instrument used to measure transpiration rate. Briefly explain how it works:

5. An experiment was conducted on transpiration from a hydrangea shoot in a potometer. The experiment was set up and the plant left to stabilise (environmental conditions: still air, light shade, 20°C). The plant was then subjected to different environmental conditions and the water loss was measured each hour. Finally, the plant was returned to original conditions, allowed to stabilise and transpiration rate measured again. The data are presented below:

Experimental conditions	Temperature / °C	Humidity / %	Transpiration / gh ⁻¹
(a) Still air, light shade, 20°C	18	70	1.20
(b) Moving air, light shade, 20°C	18	70	1.60
(c) Still air, bright sunlight, 23°C	18	70	3.75
(d) Still air and dark, moist chamber, 19.5°C	18	100	0.05

(a) Name the control in this experiment: _____

(b) Identify the factors that increased transpiration rate, explaining how each has its effect: _____

(c) Suggest a possible reason why the plant had such a low transpiration rate in humid, dark conditions:

Mesophytes, Xerophytes and Hydrophytes

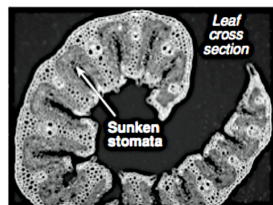
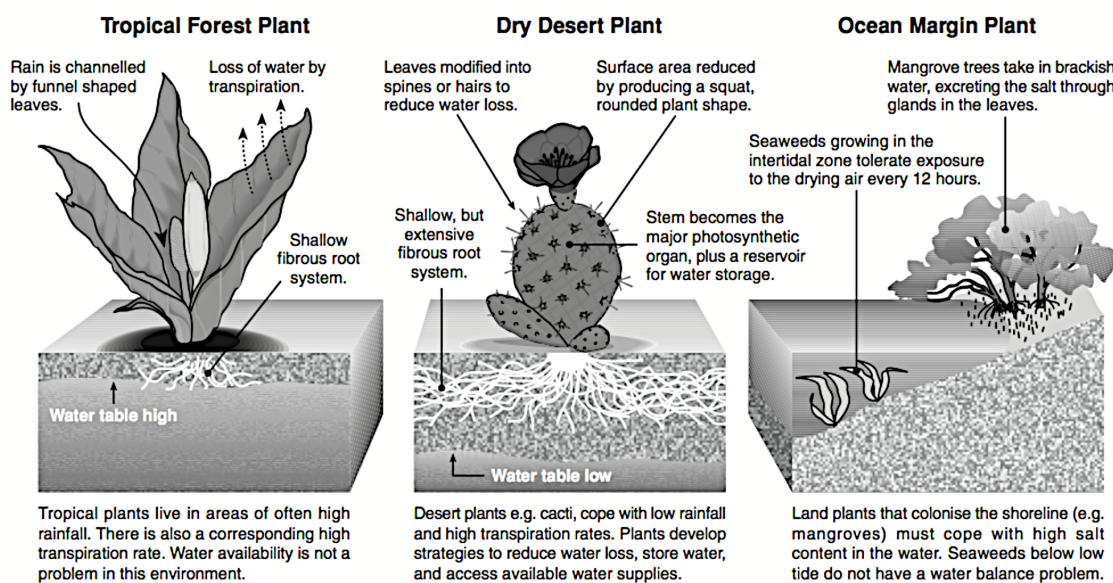
Plants can be classified on their basis of their structure in relation to the availability of water.

Mesophytes are plants found in temperate regions and they flourish in habitats with adequate water supply. They survive unfavourable times of the year by shedding their leaves, surviving underground as tubers and bulbs or as dormant seeds.

Xerophytes

Without sufficient water plant cells lose **turgor** and the tissue wilts. If a plant passes its **permanent wilting point** it will die. Water is lost from the plant by **transpiration**: the loss of water vapour, primarily through the stomata. Water balance is not a problem for aquatic plants; they allow water to flow in by osmosis until the cell wall stops further expansion. Plants

adapted to dry conditions are called **xerophytes** and they show structural (xeromorphic) and physiological adaptations for water conservation. Some of these are outlined below. Halophytes (salt tolerant plants) and alpine species may also show xeromorphic features in response to the scarcity of obtainable water and high transpirational losses in these environments.



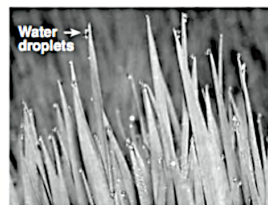
Grasses living in dry areas curl their leaves and have sunken stomata.



Mosses are poor at obtaining and storing water, restricting distribution.



Hairs on leaves trap air close to the surface, reducing transpiration rate.



Excess water is forced from leaves (guttation) during high humidity.

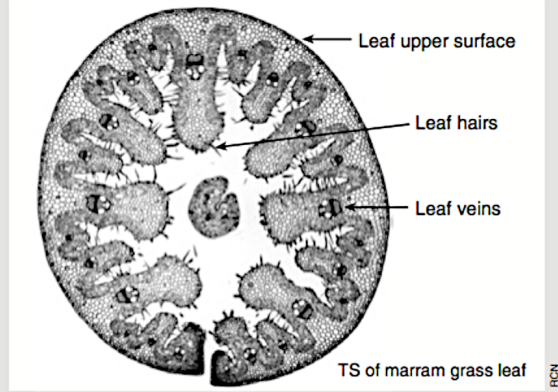
Methods of water conservation in various plant species

Adaptation for water conservation	Effect of adaptation	Example
Thick, waxy cuticle to stems and leaves	Reduces water loss through the cuticle.	<i>Pinus</i> sp. ivy (<i>Hedera</i>), sea holly (<i>Eryngium</i>), prickly pear (<i>Opuntia</i>).
Reduced number of stomata	Reduces the number of pores through which water loss can occur.	Prickly pear (<i>Opuntia</i>), <i>Nerium</i> sp.
Stomata sunken in pits, grooves, or depressions Leaf surface covered with fine hairs Massing of leaves into a rosette at ground level	Moist air is trapped close to the area of water loss, reducing the diffusion gradient and therefore the rate of water loss.	Sunken stomata: <i>Pinus</i> sp., <i>Hakea</i> sp. Hairy leaves: lamb's ear. Leaf rosettes: dandelion (<i>Taraxacum</i>), daisy.
Stomata closed during the light, open at night	CAM metabolism: CO ₂ is fixed during the night, water loss in the day is minimized.	CAM plants , e.g. American aloe, pineapple, <i>Kalanchoe</i> , <i>Yucca</i> .
Leaves reduced to scales, stem photosynthetic Leaves curled, rolled, or folded when flaccid	Reduction in surface area from which transpiration can occur.	Leaf scales: broom (<i>Cytisus</i>). Rolled leaf: marram grass (<i>Ammophila</i>), <i>Erica</i> sp.
Fleshy or succulent stems Fleshy or succulent leaves	When readily available, water is stored in the tissues for times of low availability.	Fleshy stems: <i>Opuntia</i> , candle plant (<i>Kleinia</i>). Fleshy leaves: <i>Bryophyllum</i> .
Deep root system below the water table	Roots tap into the lower water table.	Acacias, oleander.
Shallow root system absorbing surface moisture	Roots absorb overnight condensation.	Most cacti

Adaptations in halophytes and drought tolerant plants



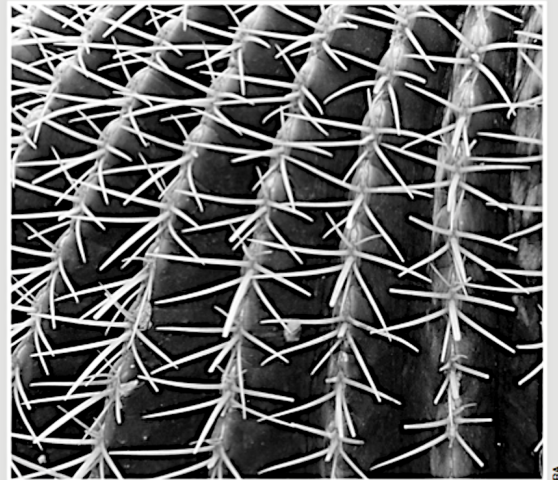
Ice plant (*Carpobrotus*): The leaves of many desert and beach dwelling plants are fleshy or succulent. The leaves are triangular in cross section and crammed with water storage cells. The water is stored after rain for use in dry periods. The shallow root system is able to take up water from the soil surface, taking advantage of any overnight condensation.



Marram grass (*Ammophila*): The long, wiry leaf blades of this beach grass are curled downwards with the stomata on the inside. This protects them against drying out by providing a moist microclimate around the stomata. Plants adapted to high altitude often have similar adaptations.



Ball cactus (*Echinocactus grusonii*): In cacti, the leaves are modified into long, thin spines which project outward from the thick fleshy stem (see close-up above right). This reduces the surface area over which water loss can occur. The stem takes over the role of producing the food for the plant and also stores water during rainy periods for use during drought. As in succulents like ice plant, the root system in cacti is shallow to take advantage of surface water appearing as a result of overnight condensation.

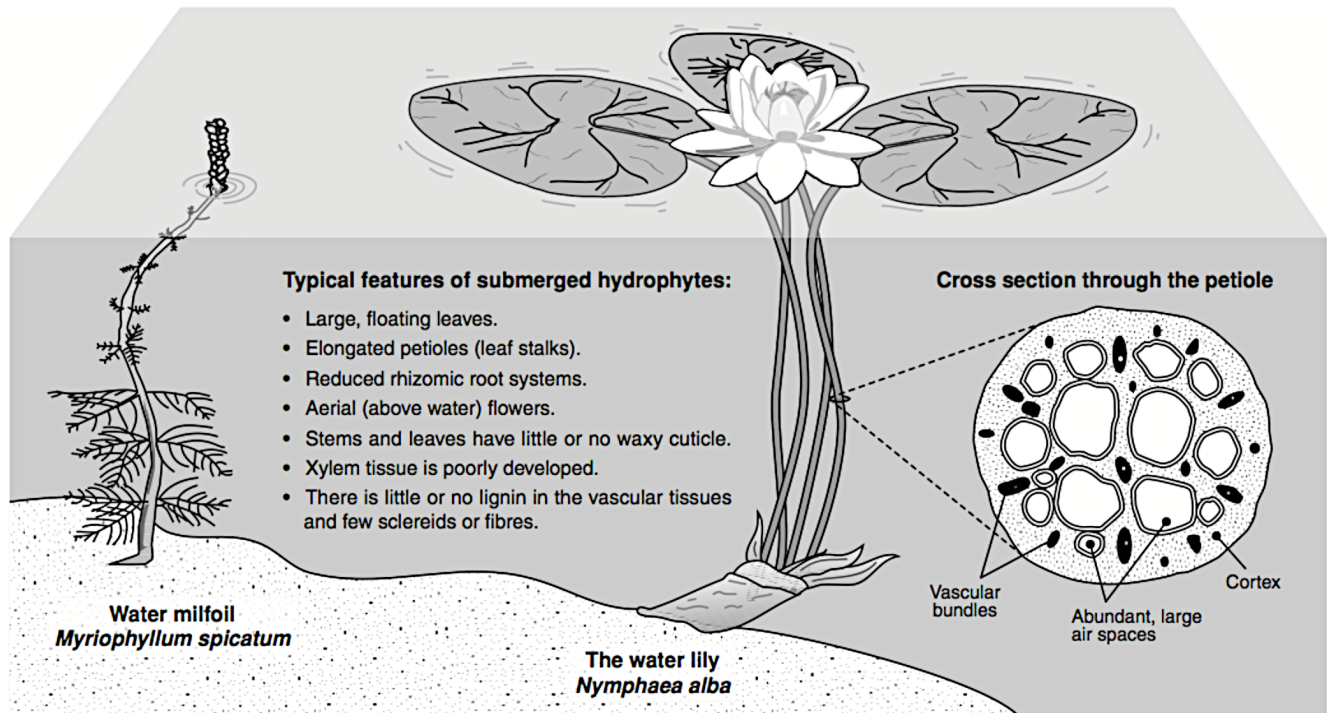


1. Explain the purpose of **xeromorphic** adaptations: _____
2. Describe three xeromorphic adaptations of plants:
 - (a) _____
 - (b) _____
 - (c) _____
3. Describe a physiological mechanism by which plants can reduce water loss during the daylight hours: _____
4. Explain why creating a moist microenvironment around the areas of water loss reduces transpiration rate: _____
5. Explain why seashore plants (halophytes) exhibit many desert-dwelling adaptations: _____

Hydrophytes

Hydrophytes are a group of plants that have adapted to living either partially or fully submerged in water. Survival in water poses different problems to those faced by terrestrial plants. Hydrophytes have a reduced root system, a feature that is often related to the relatively high concentration of nutrients in the sediment and the plant's ability to remove nitrogen and phosphorus directly from the water. The leaves of submerged

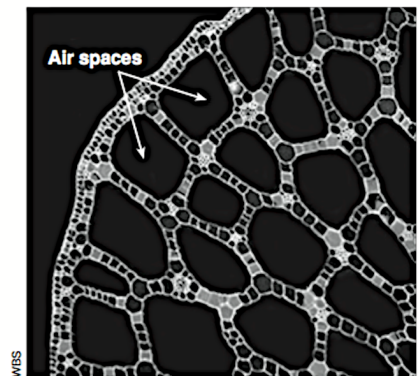
plants are thin to increase the surface area of photosynthetic tissue and reduce internal shading. Hydrophytes typically have no cuticle (waterproof covering) or the cuticle is very thin. This enables the plant ability to absorb minerals and gases directly from the water. In addition, being supported by the water, they require very little in the way of structural support tissue.



Myriophyllum's submerged leaves are well spaced and taper towards the surface to assist with gas exchange and distribution of sunlight.



The floating leaves of water lilies (*Nymphaea*) have a high density of stomata on the upper leaf surface so they are not blocked by water.



Cross section through *Potamogeton*, showing massive air spaces which assist with flotation and gas exchange.

1. Explain how the following adaptations assist hydrophytes to survive in an aquatic environment:

(a) Large air spaces within the plants tissues: _____

(b) Thin cuticle: _____

(c) High stomatal densities on the upper leaf surface: _____

2. Explain why hydrophytic plants have retained an aerial (above water) flowering system: _____